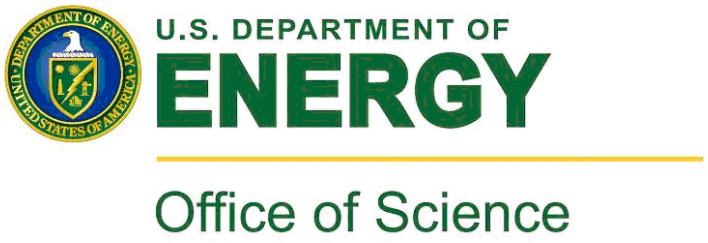

Department of Energy
Office of Nuclear Physics Report

on the

Science and Technology Review

of the

Relativistic Heavy Ion Collider (RHIC)

September 16-18, 2014

Executive Summary

The Department of Energy (DOE) Office of Nuclear Physics (NP) held a Science and Technology (S&T) Review of the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) on September 16-18, 2014. The primary purpose of the S&T review is to evaluate the quality, performance, and significance of the ongoing and planned RHIC programs in the context of the Nuclear Science Advisory Committee (NSAC) Long Range Plan for Nuclear Science and the national nuclear physics program.

The RHIC Facility is a Scientific User Facility that provides high energy heavy ion collisions as well as the world's only accelerator capable of colliding high energy beams of polarized protons for experimental research in nuclear physics. This facility has two large state-of-the-art detectors operated by the Pioneering High Energy Nuclear Interaction eXperiment (PHENIX) and Solenoidal Tracker at RHIC (STAR) research collaborations. Together, these experiments investigate collisions of heavy ions with the primary goal to study a new state of matter called the Quark-Gluon Plasma, and collisions of polarized protons to study the internal structure of the nucleon. A local theory group is associated with the facility and carries out research with a principal interest in topics relevant to the experimental program. The RHIC facility and research staff also carry out research and development (R&D) of advanced instrumentation, accelerator technology, and advanced computing.

The scientific output of the RHIC facility is very impressive, with multiple unique and significant contributions to the national Heavy Ion (HI) physics program. The complementary results and flow of ideas back and forth between the Large Hadron Collider (LHC) and RHIC is seen as a very positive development. Definitive conclusions from the first beam energy scan are limited by statistics and the plans for a second beam energy scan are well justified. The panel believes that significant results are expected from the FY14 run and upcoming runs. The panel advises that two different nuclei be collided with protons in the upcoming p-A runs in agreement with the Program Advisory Committee. The addition of Roman Pots to STAR can provide interesting measurements, but will require a dedicated experimental effort and consultation with the theory community. Impressive recent progress in the RHIC spin program has been made in the first measurements of gluon and antiquark polarizations. The RHIC spin group has played a significant leadership role in these results. The panel advises recent data sets be analyzed expeditiously and incorporated in a number of independent global analyses for a definitive measurement of the gluon polarization. A proposed determination of the sign-change in the Sivers function using W boson production appears challenging due to theoretical uncertainties. The panel expressed concern that the impressive increases in luminosity, the data acquisition strategy employed and resulting large data sets could lead to a slowdown in the data reconstruction and data-to-paper cycle. Concerns about data taking efficiency and STAR Heavy Flavor Tracker (HFT) operations remain and are the subject of recommendations.

The theory staffing levels are adequate to support the heavy ion program. While the postdoc support for lattice Quantum Chromodynamics (QCD) is weak, additional resources might be obtained through Laboratory Directed Research and Development (LDRD), Scientific Discovery through Advanced Computing (SciDAC), or other opportunities. The response to

the previous recommendation in terms of fluid dynamics is impressive and is currently the best example for the precise extraction of a fundamental parameter in QCD. The current model of sharing a spin theorist between the nuclear theory and medium energy groups is reasonable and the need for in-house expertise for the interface of theory to experiment will be important to developing the Electron Ion Collider (EIC) program.

The RHIC-ATLAS Computing Facility (RACF) is critical to the success of the RHIC experimental program. The facility is run efficiently and further gains in operations are not likely to be able to address concerns about whether sufficient computing resources are available to process all the data from FY14 and runs in the next two years. There are also concerns about the aging physical infrastructure supporting the facility. These concerns are the subject of recommendations.

The operation and maintenance of the RHIC accelerator facility are well-managed and skillfully executed. The outstanding machine performance achieved in Runs 13 and 14 attests to the strength of the organization. Activities within the Collider-Accelerator Department (C-AD) are aligned with the strategic plans of the RHIC facility and strategic goals of the Nuclear Physics program. The RHIC operations organization has in place mature and effective systems for carrying out the scheduled accelerator programs, consistent with high standards for safety and efficiency. C-AD often undertakes state-of-the-art, technically challenging projects, which have significant positive impacts on RHIC operations, but often take longer than planned to implement. Low energy electron cooling (LEReC) is required for the second beam energy scan. The proposed implementation, LEReC, now adopts technology that better aligns the accelerator R&D programs but includes substantial technical risk and potentially constrains the electron recovery linac (ERL) development. The future of RHIC, as envisioned by the laboratory, depends on success in preparing a number of new systems and techniques for the eRHIC electron-ion collider; various advisory committees have encouraged aggressive accelerator development programs for this very challenging project. The panel applauded the innovative approach in the conceptual design of eRHIC and recommended that collaboration with others be explored. The amount of time estimated for completing accelerator R&D for critical demonstrations on the overall eRHIC implementation vision seems aggressive. The panel encourages development of a plan in as much detail as possible to validate the proposed implementation schedule.

RHIC staff publications, awards, and invited presentations reflect the high level of scientific productivity of the team. The panel recognizes both the STAR and PHENIX groups as among the world's best in the field of heavy ion physics. The "paper production" of both collaborations is excellent, the choice of topics is correct and they continue to make significant impacts on the field. Members of the nuclear theory group are very highly regarded in the nuclear physics community and play an important role in the overall program. The BNL Spin Group is a recognized leader in spin physics. The collaboration between the Spin and Theory Groups has been essential for elucidating and interpreting the spin physics results at RHIC. It is desirable to restore this type of interaction to maximize the scientific output of the spin physics at RHIC. The successes of the RHIC accelerator program demonstrate the very high quality of the staff. The accelerator physicists and

engineers are world-class experts, supported by a skilled and dedicated operations team and support staff.

The RHIC Users Executive Committee (UEC) is very active in all aspects of supporting users and RHIC science; it is an excellent program. The UEC's attention is appropriately focused on the food service which is an urgent issue requiring laboratory management attention.

The strategic plan is well written and captures the present and future NP activities at BNL. The panel found the strategic plan to be comprehensive but aggressive. RHIC is being managed consistently with this plan. The panel commended management for developing contingency plans in case of changes due to external factors. RHIC management has effectively pursued "outside funding" in furtherance of the strategic plan. The process used to optimize the RHIC physics program is well informed and effectively implemented.

RHIC management is aware of the need to maintain core competencies as many technicians with unique systems knowledge near retirement; the panel urges them to continue to address this challenge. Implementation of strengthened project management is commendable and a graded approach to ensure appropriate oversight and management of various sized projects is encouraged. The panel encouraged RHIC to further utilize BNL's project management office in supplying project controls expertise. The reorganization to integrate facilities maintenance employees into RHIC operations shows evidence of realized improvements, is commended and is encouraged to be continued. RHIC's injury numbers are good and the numbers indicate the effectiveness of integrated safety management in RHICs work planning and control process.

DOE Recommendations

- Evaluate in detail the performance of the HFT, with respect to luminosity-related degradation and establish a detailed plan of operation for run 15 and beyond. Report progress at the DOE HFT quarterly status meetings.
- Prepare a report on detector data collection efficiency, estimating or measuring the contributions to the efficiency reduction. The report should report the expected limit of the average efficiency and the five most important contributors to the efficiency. This report should be submitted to DOE by January 12, 2015.
- BNL is encouraged to resolve the HVAC problem at RACF as soon as possible. Updates on plans and progress should be provided quarterly in regularly scheduled bi-weekly phone conferences with the Office of Nuclear Physics.
- The RACF and the detector collaborations should analyze the processing capacity required to perform the necessary production runs (in units of HS06*years) and compare to the available capacity of RACF. If additional capacity is required, a plan to acquire the necessary capacity by 2018 should be developed. This plan should be submitted to DOE by January 12, 2015.

Contents

Introduction

On September 16-18, 2014, the Office of Science for Nuclear Physics (NP) conducted a Science and Technology (S&T) Review of the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) in Upton, New York.

The review panel consisted of eight external peer review experts: Dr. Rodney Gerig (Argonne National Laboratory, retired); Dr. John Corlett (Lawrence Berkeley National Laboratory); Dr. Roger Erickson (SLAC National Laboratory); Professor Thomas Schaefer (North Carolina State University); Professor Mark Strikman (Penn State University); Professor Bolek Wyslouch (Massachusetts Institute of Technology); Dr. Robert Varner (Oak Ridge National Laboratory); Professor Jen Chieh-Peng (University of Illinois, Urbana-Champaign). The review was chaired by Dr. James Sowinski, Acting Program Manager for Heavy Ion Nuclear Physics, Office of Nuclear Physics. Dr. Jehanne Gillo, Director of the Facilities and Project Management Division in NP was responsible for the review. Dr. Timothy J. Hallman, Associate Director of the Office of Science for Nuclear Physics; Dr. George Fai, Program Manager for Nuclear Theory; Dr. Gulshan Rai, Program Manager for Medium Energy Nuclear Physics; Dr. Elizabeth Bartosz, Program Manager for Nuclear Physics Instrumentation; Dr. Manouchehr Farkhondeh, Program Manager for Advanced Technology Research and Development; and Dr. Michelle Shinn from the Office of Nuclear Physics attended as well.

The primary purpose of the S&T review is to evaluate the quality, performance, and significance of the ongoing and planned RHIC programs, in the context of the Nuclear Science Advisory Committee (NSAC) Long Range Plan for Nuclear Science and the national nuclear physics program. In order to perform the review, each consultant was asked to evaluate and comment on any relevant aspect of the science and technology at the RHIC, facility operations and strategic planning. Specifically, the focus of the Science and Technology Review was on understanding:

- The quality, productivity, and significance of the laboratory's scientific and technical accomplishments and the merit, feasibility and impact of its future planned physics program;
- The effectiveness and appropriateness of facility operations and the planning for future facility upgrades in support of the research program;
- The effectiveness of management in strategic planning, developing appropriate core competencies, implementing a prioritized and optimized program, and promoting and implementing a safe work environment;
- The leadership, creativity, and productivity of the facility's scientific and technical staff in carrying out the above activities; and
- The quality and appropriateness of the laboratory's interactions with, and nurturing of, its scientific community.

In addressing these charge elements, the reviewers were also asked to comment on what progress had been made towards addressing action items from the previous S&T Review as well as the 2013 Facility Operations Review. Prior to the review, BNL had provided

background material to the panel reviewers, including copies of the 2011 RHIC S&T Report, the Response from BNL/RHIC management regarding the 2011 S&T DOE Recommendations, as well as the 2013 Facility Operations Review Report.

The review was based on formal presentations given by the RHIC management, operations and research staff, and detailed discussions with the BNL staff, and on the panel members' extensive experience. The first day covered an overview from the Associate Laboratory Director (ALD) for Nuclear and Particle Physics, Dr. Berndt Mueller, plenary presentations on scientific progress, facility and experiment operations, planned upgrade projects for both instrumentation and the accelerator, and an update on the progress of the proposed eRHIC Facility. The second day started with presentations on BNL research groups' contributions to the RHIC scientific program followed by individual reports from Safety Management and from the RHIC Users' Executive Committee. Parallel breakout sessions in the afternoon provided a forum for the assigned teams of panel reviewers to obtain further information and discuss particular issues with BNL staff.

Question and Answer (Q&A) sessions and executive sessions were held throughout the review. A verbal briefing of preliminary findings, comments and recommendations was presented to Dr. Berndt Mueller and other BNL staff upon the conclusion of the review on the third day. The panel members were asked to submit their individual evaluations and findings in a "letter report" covering all aspects of the RHIC program. The executive summary and the accompanying recommendations are based largely on the information contained in these letters reports. Appendix A lists the recommendations from the 2011 RHIC S&T Report and the 2013 Facility Operations Review and the current status of each. A copy of the charge letter and the agenda are included in Appendix B and Appendix C, respectively.

Scientific Program

Experimental Program

Findings:

The RHIC collaborations continue to analyze and release heavy ion data collected in runs prior to 2013. They made multiple improvements to analysis techniques, e.g. direct photon measurements in the Pioneering High Energy Nuclear Interaction eXperiment (PHENIX), and the detection of heavy flavor in the Solenoidal Tracker at RHIC (STAR).

The PHENIX and STAR experiments continue to publish at a rate of ~ 1-2 papers per month per experiment, some of the recent physics highlights include

- High statistics measurements of direct photon yield and v2 in Au+Au, and the first measurement of direct photon v3 in Au+Au. These measurements challenge the existing hydrodynamic description of the collision.
- Measurement of Y(1S+2S+3S) R_{AA} in Au+Au. The measurement indicates strong suppression of the upsilon (Y), consistent with the Compact Muon Solenoid (CMS) result.
- First Direct D^0 reconstruction which can be used to study suppression of heavy quarks.
- Net-proton kurtosis which possibly indicates a transition between the hadronic and partonic phases.

In addition, the analysis of the first beam energy scan is almost complete. Initial results indicate that hadronic matter dominates below 11.5 GeV and partonic interaction above 39 GeV.

The STAR and PHENIX experiments added new sub-detectors (Heavy Flavor Tracker (HFT), Muon Telescope Detector (MTD), and Forward Vertex or (FVTX)) that enhance their ability to study heavy quarks and quarkonia. New detectors operated properly during Run 14 and appear to have achieved their design specifications. The HFT pixel detector did encounter radiation-field related problems during the first two weeks of Run 14 that caused damage to sensors in the inner ladders. The problem was fixed by lowering the latchup thresholds per ladder, and performing an automatic reset every 15 minutes. The efficiency of the detector initially decreased during the run (in the first three weeks) by about 15%, but after the improved operational procedures were put in place very little additional damage was acquired in the subsequent 2.5 months of running with Au+Au at 200 GeV.

The planned RHIC proton – nucleus (p-A) run will provide key information on the interaction of partons at high gluon densities, including first information ever on the A-dependence of the transverse spin effects. It would complement in many ways the previous deuteron – gold runs and provide critical information for the understanding of the change of the interaction dynamics with energy.

There is large effort proposed to design and build sPHENIX that will replace the existing detector. The emphasis of the new apparatus is on jets and heavy quarks. The proposed plan is to have a 4-5 year shutdown of PHENIX while it is upgraded and then take data

during FY 2021 and FY 2022. Plans for upgrading the PHENIX detector to sPHENIX make use of the superconducting solenoid magnet salvaged from the BaBar detector, as well as numerous improvements in the detector, signal processing, and data-handling technologies.

There was an FY 2011 S&T Review recommendation requesting a report about the detector efficiencies which was provided. The detector data collection efficiency for each detector is reported to be currently around 80%. Both STAR and PHENIX experiments take data at the limit of their data acquisition (DAQ) systems (2 kHz and 7 kHz respectively). Their trigger systems are optimized to collect rare probes with no or minimal down scaling and as much minimum bias data as possible. In run 14 STAR used the high level trigger to maximize HFT acceptance.

The integrated luminosity for the longitudinally polarized p+p run at 510 GeV from Run 13 has exceeded all previous p+p runs combined, as a result of the installation of a new polarized source and a new superconducting solenoid. This significant improvement in the accelerator performance is essential for the RHIC-spin physics program.

From the measurement of longitudinal double-spin asymmetry for single-jet and π^0 production in Run 9, evidence for a positive gluon polarization in the region $0.05<x<0.2$ is reported for the first time. Measurement of longitudinal spin asymmetries (A_L and A_{LL}) for W boson production from Runs 11 and 12 has provided evidence for the flavor asymmetry of polarized sea-quark distributions for up and down antiquarks in the proton. The feasibility for measuring A_N for W boson production with transversely polarized p+p at 510 GeV from 2011 run was shown. This suggests the possibility of testing the QCD prediction for the Q^2 evolution of the Sivers function at RHIC.

The focus of the medium-energy group's current research interest is on the transverse-spin physics and polarized p-A collisions. The group is responsible for the operation of the polarimeter, and the installation of the Roman Pot detector for STAR, which is important for the polarized p-A program. An important study of the spin effects was performed by the medium energy group – they suggested a method to use ultra-peripheral collisions of polarized protons and nuclei with exclusive production of J/ψ off the proton to measure the generalized gluon distribution in the nucleon, a measurement not accessible in the case of unpolarized scattering. The measurement will use the Roman Pot detector installed at STAR.

Comments:

The scientific output of the RHIC facility is very impressive, with multiple unique and significant contributions to the Heavy Ion (HI) physics program. Several analyses were completed in response to new LHC results, e.g. reanalysis of dAu correlations or J/ψ and Upsilon suppression. This is a very positive development. The LHC experiments are benefitting from the long list of RHIC results. The definitive conclusions from the beam energy scan are currently limited by statistics, especially at the lower energies. Planning for a second beam energy scan is very justified. Significant new results from the 14 run can be expected, as well as from the p-A and Au-Au runs in the near future, in particular in the area of heavy quark production. However, the impressive increase of luminosity coupled with

the "max DAQ" strategy will result in very large data sets in the future and the resultant slowdown in reconstruction and data-to-paper cycle.

The analysis of the LHC p-A data have found that it is very difficult to determine the centrality of the events based on the measurement of the hadron production in spite of a very large acceptance of the A Toroidal LHC Apparatus (ATLAS) and CMS detectors. To understand the origin of the non-linear effects observed for the forward hadron production in d-Au collisions, it is highly desirable to have data for p-A collisions with at least two nuclear beams, as recommended by the Program Advisory Committee (PAC). To consider the PAC recommendation, modeling of the merits of two and one nucleus scenarios of the p-A run for maximizing non-linear effects – a better statistics with one nucleus vs. selection of central collisions using Pb and Al data sets – should be performed.

Use of the Roman Pot system can provide interesting measurements, such as a) the inelastic diffraction cross section in p-p scattering at small t, which is critical for Gribov-Glauber type models of p-A scattering, b) and the ratio of the coherent diffraction cross sections in p-A and p-p scattering. However, dedicated effort will be required in order to ensure that the Roman Pot system performs adequately to implement the science. It is important to provide theorists interested in the diffractive studies in p-p and p-A scattering with more detailed information on the 2D acceptance of the Roman Pot system; discussion of the current plans of the run (triggers, etc.) with theorists could optimize productivity. Exploration of the potential of forward calorimetry for testing various models of the forward hadron production in p-A scattering would be useful.

The operation of the STAR HFT pixel detector during high luminosity runs in FY15 and FY16 is a concern. The detector performance changed significantly during run 14, e.g. the number of working channels at the end of the run was 10% lower than at the beginning. A reset every 15 minutes does not seem to be a robust solution to latch-up problems. This merits careful attention by the BNL group and management.

The detector efficiency response to the FY 2011 recommendation was detailed, but difficult to clearly interpret. Some important parts of the response were too qualitative to understand the limits on efficiency imposed by detector design and running requirements. A clear, quantitative understanding of the efficiency limitations would help the panel better understand this topic. The panel notes that this topic has been the source of concern at multiple prior S&T reviews.

The use in the sPHENIX proposal of the BaBar solenoid from SLAC is commendable as a cost savings measure.

Impressive recent progress in the RHIC spin program has been made in the first measurements of gluon and antiquark polarizations. The RHIC spin group has played a significant leadership role so far, and is encouraged to interact actively with various polarized parton distribution functions (PDF) global-fit groups to obtain independent extractions of the gluon and sea-quark polarizations. To reach a definitive measurement on the magnitude and sign of the gluon polarization (DOE HP12 performance milestone), it is

imperative to analyze the additional data collected in 2011-2013 expeditiously and to have independent global analyses carried out by different groups to extract the values and uncertainties of $\Delta g(x)$.

The Department of Energy (DOE) Hadron Physics 8 (HP8) performance milestone (2013) has been successfully reached with the single spin asymmetry (A_L) measurement for W boson production at 510 GeV. The high statistics data collected in 2013, together with the 2011+2012 data which have already been analyzed, are expected to provide a definitive measurement of the up and down sea quark polarizations. A definitive measurement of the sign-change of the Sivers function via the A_N of W production (DOE HP13 performance milestone) appears to be quite challenging, primarily due to the theoretical uncertainties in transverse momentum dependent (TMD) evolution.

Recommendations:

- Evaluate in detail the performance of the HFT, with respect to luminosity-related degradation and establish a detailed plan of operation for run 15 and beyond. Report progress at the DOE HFT quarterly status meetings.
- Prepare a report on detector data collection efficiency, estimating or measuring the contributions to the efficiency reduction. The report should report the expected limit of the average efficiency and the five most important contributors to the efficiency. This report should be submitted to DOE by January 12, 2015.

Theoretical Program

Findings:

The nuclear theory effort at Brookhaven National Laboratory (BNL) currently consists of nine long term members (after the departure of one member in 2014), of whom two are in half-time appointments, and two are in tenure-track appointments. The main effort is devoted to the heavy ion program. Three staff members work on lattice quantum chromodynamics (QCD), with an emphasis on hot and dense QCD. Currently one staff member works on the spin program, as did the departed member.

The main results presented at the review are a complete hydrodynamic description of higher harmonics of flow starting from a model of fluctuating initial conditions, the extraction of freezeout parameters using lattice QCD results on charge fluctuations, and a global QCD analysis of polarized parton distributions which includes the new polarized p-p data. For the first time, the evidence has emerged for polarization of gluons in the proton.

The previous science and technology (S&T) review report included a recommendation that the theory group should identify a small number of quantities for important experimental observables and consider focusing some of its efforts on producing quantitative predictions that can be used for precise theory-data comparisons. The theory group decided to focus on fluctuations observables.

Comments:

The theory staffing levels are adequate to support the heavy ion program. Given the needs of the experimental spin physics group in identifying suitable observables and precision goals, a continuation of the current model of sharing a spin theorist between the nuclear theory and medium energy groups is reasonable. The spin program is one of the major thrusts of the proposed Electron Ion Collider (EIC) in RHIC (eRHIC) program; however, currently the spin program does not have strong in-house expertise for the interface of theory to experiment. The current postdoc support for the lattice QCD program is weak, but given the standing of the group, and its role in providing software support for lattice QCD computing, it is likely that additional resources can be obtained using Laboratory Directed Research and Development (LDRD), Scientific Discovery through Advanced Computing (SciDAC), or similar opportunities.

The response to the previous recommendation in terms of fluid dynamics is very impressive and is currently the best example for the precise extraction of a fundamental parameter in QCD, the shear viscosity to entropy density ratio, from heavy ion data at RHIC and the Large Hadron Collider (LHC).

The study of the effects related to the transverse proton polarization in p-A will require sophisticated theoretical studies bridging between the parton nucleon structure effects and effects of propagation of partons through nucleon/nucleus gluon fields.

A significant increase of the experimental statistics and extension of the x-range would substantially improve the accuracy of the Δg extraction. In view of the small value of the observed A_{LL} asymmetry, further studies of the dependence of single jet production on the jet algorithm are desirable. In addition it is suggested to study possible spin dependence of the underlying event effects. To further understanding of the spin dynamics, the scope of the spin effects studies should be extended beyond the inclusive measurements.

Recommendations:

- None

RHIC-ATLAS Computing Facility (RACF) - Computing

Findings:

The RACF provides most of the computing needs for RHIC experiments; it is shared with ATLAS Tier 1 operations. It is constructed with large emphasis on network, scalability, and uniformity between experiments. The RACF has been operating with a fixed budget and staff. Resource allocation is determined in detailed discussions with the experiments, with some possibility of temporary reallocation of the central processing units (CPU).

The RACF operates with 4.2 fewer full-time equivalents (FTE's) and $0.5 million less equipment than planned several years ago. Operating the RHIC computing facility and the U.S. ATLAS Tier 1 computing facility together reduces the total staff required by using their combined expertise for both facilities. It has operated with no unplanned down time

during runs, except for heating, ventilating, and air conditioning (HVAC) failures. Aging utilities in the computer center, especially cooling, are failing several times per year. BNL is considering transforming the former NSLS building into a modern data center.

The RACF uses a 4-5 year technology refresh basis. The spending for technology updates is driven by detector concerns for storage, bandwidth or processing. The continuing technology refresh and CPU and storage upgrades will exceed available capital resources in 2018 by $500,000 under the current spending plan.

The RACF data storage system has been able to cope with the luminosity and DAQ improvements, with up to 100 TB/day written to tape. The required storage for PHENIX and STAR raw data for the next 5 years has been estimated to be 9120 TB (2014), 8200 TB (2015), 9300 TB (2016), 2784 TB (2018), and 2650 TB (2019). These data will not exceed the planned capacity of the RACF.

Comments:

The RACF is critical to the success of the RHIC experimental program. It does an efficient job of providing services in an environment of constrained resources, leveraging highly parallel systems of relatively inexpensive components and shared expertise with ATLAS to reduce required workforce and reduce cost. Reduced funding in computing has encouraged excellent efficiencies in operation that have probably reached the limits of what can be obtained.

Each of the next two years of data taking may take as much data as in Run 14. While there is enough capacity to store the data, it is not clear that there is enough computing capacity in the RACF to process all the data for STAR and PHENIX. Analyzing this problem is not easy because the processing requirements of STAR and PHENIX and the processing capabilities of RACF are not expressed in common units.

The aging physical plant, in particular unreliability of the HVAC systems threatens the reliability of RACF operations. Securing enough Instructional General Plant & Projects financing for the upgrade has been a problem.

Recommendations:

- BNL is encouraged to resolve the HVAC problem at RACF as soon as possible. Updates on plans and progress should be provided quarterly in regularly scheduled bi-weekly phone conferences with the Office of Nuclear Physics.
- The RACF and the detector collaborations should analyze the processing capacity required to perform the necessary production runs (in units of HS06*years) and compare to the available capacity of RACF. If additional capacity is required, a plan to acquire the necessary capacity by 2018 should be developed. This plan should be submitted to DOE by January 12, 2015.

Facility Operations and Planning for Future Facility Upgrades

Findings:

The technical capabilities of the RHIC facility have continued to expand, extending the science reach. Among the noteworthy improvements are a new ion source and a 3-D stochastic cooling system. Multiple improvements to the accelerator systems resulted in increased instantaneous luminosity, luminosity lifetime and accelerator chain reliability beyond original estimates. The luminosity, in both the ion-ion (A-A) and polarized proton-proton (p-p) modes, has increased substantially in recent years, such that the integrated luminosity for polarized p-p in Run 13 and Au-Au in Run 14 exceeded the combined totals of all previous runs. In addition there were more specialized runs: ^{3}He+Au and a 15 GeV Au-Au run.

The actual running time for experimental data-taking has been limited to about 17 weeks per year, due to funding constraints. However, machine availability has remained high, in the mid-80 percent range, even as new features have been added and the technical capabilities have been extended. In addition, unproductive but unavoidable end-effect time during beam operations, including the time needed to set up and tune beams, has been significantly reduced. Cost per pb^{-1} has decreased a factor of 1000 over ~14 years.

Staffing levels supporting the RHIC accelerator program have remained fairly constant. The demographic distribution of staff members shows a large number of staff members, especially technicians with extensive experience and critical skills, whom are within about 10 years of retirement.

Aging conventional infrastructure, particularly the electrical distribution cables and switchgear, poses a risk to future projects, as well as ongoing operations. This is a site-wide issue of which BNL management is aware.

A number of AIP projects are underway or proposed. Operation of electron lenses was demonstrated in Run 14 on ^{3}He beam, in preparation for operations with protons. Low-Energy RHIC electron Cooling (LEReC) is proposed and is expected to improve luminosity by up to a factor of 10. A new Accelerator Improvement Project (AIP) project "Accelerator Technical Infrastructure Upgrade" is being proposed.

The eRHIC conceptual design makes use of several state-of-the-art or unproven techniques, including a multi-pass Energy Recovery Linac (ERL) scheme, coherent electron cooling, a novel Fixed Field Alternating Gradient (FFAG) lattice to simultaneously transport several beams of widely differing energies, and a Gatling gun high charge source. The initial eRHIC design is for a luminosity of $10^{33}/cm^{2}s^{-1}$, with upgrade options offering factors of 10–100 greater luminosity.

Comments:

The operation and maintenance of the RHIC accelerator facility are well managed and skillfully executed. The outstanding machine performance achieved in Runs 13 and 14

attests to the strength of the organization. The accelerator and detector operations teams have managed to collect large data sets, outpacing the computing and analysis capabilities of the physics collaborations, despite the limitations on running time each year.

Activities within Collider-Accelerator Department (C-AD) are aligned with the strategic plans of the RHIC facility and strategic goals of the Nuclear Physics program. The RHIC operations organization has in place mature and effective systems for carrying out the scheduled accelerator programs, consistent with high standards for safety and efficiency. Implementation of machine upgrades and attention to minimizing setup time, such as well-developed beam-based feedback systems, have led to recent operational successes. Recent improvements have led to meeting the goal of luminosity lifetime dominated by burn-off.

C-AD often undertakes state-of-the-art, technically challenging projects, which have significant positive impacts on RHIC operations, but often take longer than planned to implement.

The LEReC design has evolved from using the Fermilab pellatron existing equipment to using "in-house" components under development as part of the eRHIC ERL research and development (R&D) program. The LEReC project now adopts technology under development for eRHIC and better aligns the accelerator R&D programs. However, the project includes substantial technical risk and potentially constrains the ERL development.

Beyond a ten-year horizon, the future of RHIC, as envisioned by the laboratory, depends on the success in preparing for the eRHIC electron-ion collider, including demonstrating the viability of the multipass ERL concept, coherent electron cooling, a novel beam transport system, and high performance gun designs. Various technical advisory committees and reviews have encouraged aggressive accelerator development programs for this very challenging project.

The conceptual design of eRHIC with the existing blue RHIC ring and an electron beam using ERL+FFAG rings is applauded as an innovative approach. The accelerators are complex, however, and continued design studies are very important. The possibility of a collaboration with Cornell in ERL/FFAG demonstration is encouraging, and the panel recommends this be further explored as a means to expedite progress and potentially share costs.

Demonstrations of key physics and technology have made some progress over the past several years. The amount of time estimated for completing accelerator R&D for critical demonstrations on the overall eRHIC implementation vision, in the context of potentially constrained resources, seems aggressive. The panel encourages development of a plan in as much detail as possible (technical approach, resources, cost, schedule) for eRHIC R&D and critical performance demonstrations and milestones, to validate the proposed eRHIC implementation schedule.

In a previous review, a concern was raised about the future availability of type 7835 power amplifier tubes needed for the linac, because only one vendor still makes these tubes. With

a five-year inventory in stock at BNL, and applicable new radio frequency (RF) power sources being developed at other DOE labs, this issue appears to be under control.

Recommendations:

- None

Scientific and Technical Staff

Findings:

Experiments are operated with large contributions from BNL staff. The complexity of both experiments has increased with time due to addition of new large subdetectors and upgraded DAQ. In both groups about 40% of staff is dedicated to day-to-day running of the experiments as well as maintenance and upgrades.

The C-AD provides 340 FTEs in support of RHIC operations and upgrades, and staff is proposing a transition to eRHIC in the next decade. The C-AD continues to develop project planning capabilities with new staff and tools.

The BNL staff holds a large fraction of top managerial positions in both experiments. They provide scientific leadership in ~50% of published papers. The PHENIX BNL research group has had 11 principal authors on the 24 refereed papers published by PHENIX in the past year. Group members presented 55 invited talks, have served on 9 review committees, and have organized or are organizing 9 conferences. The STAR BNL research group has had 15 principal authors on the 22 papers published by STAR in FY 2013 and FY 2014. A group member has received a DOE Early Career Award and another group member received a Goldhaber fellowship. Group members presented a total of 51 talks, with 24 invited talks, in the past year and have organized or are organizing 8 conferences. In the past 12 months, the RHIC spin group members have delivered 47 invited talks and have organized 9 Conferences/Workshops. Eleven refereed papers (4 EIC, 4 PHENIX-spin, and 3 STAR-spin) have been published in the past 12 months.

Comments:

RHIC staff publications, awards, and invited presentations reflect the high level of scientific productivity of the team. The "paper production" of both collaborations is excellent; this indicates that their teams are well organized and well-motivated. The choice of topics is correct and they continue to make significant impacts on the field of heavy ion (HI) physics. Both STAR and PHENIX groups are among the world's best in the field of HI physics.

Members of the nuclear theory group are very highly regarded in the nuclear physics community. They have played an important role in formulating the physics case for a possible future EIC, and in making connections between lattice QCD and heavy ion observables.

The BNL group is a recognized leader in spin physics. In addition to their support for the polarimeter at RHIC-spin, the group members are instrumental in steering the spin physics programs at RHIC, in initiating the transverse spin program with W production, and in articulating the spin physics opportunities at eRHIC. The collaboration between the RHIC Spin Group and theory was essential for elucidating and interpreting the spin physics results at RHIC. It is desirable to restore this type of interaction to maximize the scientific output of the spin physics at RHIC.

The successes of the RHIC accelerator program, including remarkable improvements in machine performance in several modes of operation, demonstrate the very high quality of the staff. The accelerator physicists and engineers are world-class experts, supported by a skilled and dedicated operations team and support staff.

Recommendations:

- None

Scientific Community

Findings:

The RHIC Users Executive Committee (UEC) responds to user needs on issues regarding quality of life and access to the laboratory. In addition, it helps to popularize RHIC research to media and actively recruits users to promote the cause of RHIC in Congress.

In the FY 2011 S&T review, there was a finding that the users expressed strong dissatisfaction over the current housing situation at BNL. The UEC lobbied with management to improve housing in some ways over the past few years. The UEC worked with other facility UEC's to collect 1000 responses to a survey on housing in 2012.

There may be hundreds of visitors on site on the weekends during especially busy times. The food service on site on weekends and evenings has been shutdown, starting in August 2014. The UEC has sent a statement to management expressing the need for these services. Six hundred users signed the statement.

Comments:

The UEC is very active in all aspects of supporting users and the cause of RHIC science. It is an excellent program.

The UEC focus has shifted from housing challenges to food service challenges. The food service issue is quite urgent, deserves the effort the UEC is putting into it, and requires laboratory management attention. It was unclear to the panel as to whether there were remaining housing issues to be dealt with from the UEC perspective.

Recommendations:

- None

Management

Findings:

The most recent Strategic Plan was written in Oct. 2013; and is titled, "RHIC Transition to eRHIC Plan." This plan was made available to the panel. The plan addresses prioritization and optimization in completing the RHIC mission, the role of sPHENIX, and planning for an Electron-Ion Collider (EIC) utilizing RHIC infrastructure. The strategic plan includes a section on engaging the support of the NP community behind an EIC. Program Optimization was also addressed in detail in "RHIC Operations Review 2013 Response B_Program Optimization." The decisions of RHIC management are presently being guided by this most recent strategic plan and management has thought through a number of alternatives to the plan, including scenarios in which an EIC would be modestly delayed.

RHIC has been effective in pursuing "outside funding" e.g., LDRD, program development funds, IGPP, SCIDAC, and contributions from collaborators.

RHIC is tracking age demographics. There have been active attempts to hire junior and critically-needed staff to fill key slots. American Recovery and Reinvestment Act of 2009 (ARRA) funding, in particular, was used to hire engineers in C-AD.

The group which does facilities maintenance has been reorganized and better integrated into the operation of the RHIC facility.

Management believes that the BNL housing problems, discussed at the last S&T meeting, have been resolved. However, the concerns regarding food service, presented at this review, is a significant problem that needs to be resolved.

Injury numbers were reported as follows: Total recordable cases: (TRC) and Days Away, Restricted work activity, and/or job Transfer (DART) are low and improving with favorable downward trends.

Comments:

The strategic plan is well written and captures the present and future Nuclear Physics (NP) activities at BNL. The sections include: Completing the RHIC Mission, The Role of sPHENIX, eRHIC Accelerator Design, Realizing eRHIC, eRHIC Detector Plans, and Engaging the EIC community. RHIC is being managed consistently with this plan.

The panel found the strategic plan to be comprehensive but very aggressive. The laboratory is managing to this aggressive schedule, in part, to retain and attract junior staff and the best talent. External factors such as the recompete of the BNL contract, the release of the NP Long Range Plan, etc., will likely lead to changes in the plan. The Laboratory has thought through options for a number of cases. Among them is an additional spin run prior to the installation of the low energy e-cooling. Another is additional runs after sPHENIX is installed. In each instance a case for the physics, beyond that in the present plan, was made and claimed to be compelling. The Laboratory management is commended for developing these contingency plans.

RHIC management has effectively pursued "outside funding" and has effectively applied it in ways consistent with the strategic plan.

The content in the presentations on the development and retention of core competencies claimed that the actions taken have led to adequate core capabilities going forward. The data shown did not reveal glaring problems. However, there are many technicians nearing retirement, and often these individuals have unique knowledge of the systems they maintain, and this information needs to be transferred to junior technicians. RHIC management is aware of this, and should continue to address this challenge.

Implementation of strengthened project management is commendable and a graded approach to ensure appropriate oversight and management of various sized projects is encouraged. RHIC is beginning to utilize BNL's project management office in supplying project controls expertise. The panel encourages this utilization.

Program optimization utilizes many high level, as well as more detailed inputs. These include uniqueness of RHIC capabilities, and an understanding of work being done elsewhere; Likelihood of success; Input from community; Machine upgrades and performance. Overall the panel believes that the process used to optimize the RHIC physics program is well informed and effectively implemented.

The reorganization that better integrates facilities maintenance employees into RHIC operations is to be commended. There is strong evidence of realized improvements from this reorganization, and this is encouraged to be continued.

RHIC's low injury numbers are very good. A number of the incidents are not work related, and although these are still to be minimized, the numbers indicate the effectiveness of integrated safety management in RHICs work planning and control process.

Recommendations:

- Repeat from FY 2013 Operations Review: Formalize tracking and reporting of a reasonable set of activity-based analytical metrics representing aspects of RHIC operations. Provide to DOE/NP by mid-October 2014.

Appendix A: Action Items from 2011 Science and Technology Review and Action Items from 2013 Facility Operations Review

Facility Operations Review 2013

- Develop a mitigation plan to improve the reliability and reduce the programmatic risk of three accelerator systems: Booster transformers, AGS motor-generator, and linac RF power tubes ("7835") by November 2013.
- Formalize tracking and reporting of a reasonable set of activity-based analytical metrics representing aspects of RHIC operations. Provide to DOE/NP a draft report by December 2013.
- Use the to-be-established management process to document a rationale for program optimization to DOE/NP by December 2013.
- Work with the laboratory to develop a plan to consolidate the buildings associated with RHIC. Report plan to DOE/BHSO and DOE/NP by end of October 2013.

Science and Technology Review 2011

- Generate a concise report that articulates the status of polarimetry capabilities, which evaluates remaining risks and challenges, and identifies needed resources. Deliver to the Department of Energy (DOE) by January 2, 2012.
- RHIC management should identify in detail where the running efficiencies are lost and develop a plan articulating how they will address these inefficiencies, with a goal of reaching running efficiencies of at least 85%. Submit the plan to DOE by January 2, 2012.
- Review and clarify the roles and responsibilities of RHIC and the detector collaborations for maintaining and operating detectors and their upgrades and resolve the appropriate funding mechanisms. Conduct a bottom-up exercise of the current and anticipated experimental support needs for RHIC, explaining and justifying the staffing levels. Submit the results to DOE by January 2, 2012.
- Prepare a commissioning plan for the eLens project, which describes commissioning personnel and activities, and durations of tasks and goals in the context of the overall RHIC operations. Present the plan at the next DOE eLens review.
- The nuclear theory group should identify a small number of quantities for important experimental observables and consider focusing some of its efforts on producing quantitative predictions that can be used for precise theory-data comparisons. These results should be presented at the next S&T review.
- BNL management should address user concerns regarding housing upfront and openly so that users know what to expect; a process needs to be developed lab-wide that gives users access to on-site housing. Report progress to DOE at the bi-weekly conference calls.

Appendix B: Charge Memorandum

Thank you for agreeing to participate as a panel member for the biennial Science and Technology (S&T) Review of the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) which will take place at BNL on September 16-18, 2014. A list of the members of the review panel and anticipated Department of Energy (DOE) review participants is enclosed.

The RHIC facility plays an essential role in two major scientific thrusts of the U.S nuclear physics program, the national heavy-ion program and spin physics program. As the primary sponsor of U.S. nuclear physics research and the operations of RHIC, it is important for the Office of Nuclear Physics to understand the progress and future potential of these two research programs, the effectiveness of RHIC operations and whether resources and planning are being directed optimally to achieve the scientific goals of the Nation's nuclear physics program.

In carrying out this charge, each panel member is asked to evaluate and comment on:

- The quality, productivity, and significance of the laboratory's scientific and technical accomplishments and the merit, feasibility and impact of its future planned physics program;
- The effectiveness and appropriateness of facility operations and the planning for future facility upgrades in support of the research program;
- The effectiveness of management in strategic planning, developing appropriate core competencies, implementing a prioritized and optimized program, and promoting and implementing a safe work environment;
- The leadership, creativity, and productivity of the facility's scientific and technical staff in carrying out the above activities; and
- The quality and appropriateness of the laboratory's interactions with, and nurturing of, its scientific community.

The Laboratory should also comment upon what progress has been made towards addressing action items from the previous S&T Review as well as the Facility Operations Review conducted last fiscal year.

The first and second day will consist of presentations by the laboratory and executive sessions. The third day will be used for an executive session and preliminary report writing; a brief close-out will take place in the early afternoon. Preliminary findings, comments, and recommendations will be presented at the close-out.

Each panel member is asked to review these aspects of RHIC and write an individual "letter report" on his/her findings. These letter reports will be due at DOE two weeks after completion of the review. The review will be chaired by Dr. James Sowinski, Acting Program Manager for Heavy Ion Nuclear Physics for the Office of Nuclear Physics. As Chairperson for the review, he will accumulate the "letter reports" and compose a final summary report based on the information in the letters. We take care to keep the identity of the reviewers confidential in the summary report. It would be convenient if you would

prepare your response in a form suitable for transmittal to the proponents devoid of potentially identifying information. The cover letter may include other remarks you wish to add. We will collate the comments and recommendations from these letter reports and compose a summary report based on the information in the letters.

An agenda and background material, as well as travel and housing information, will be sent to you directly from BNL. The laboratory will make word processing and secretarial assistance available during the review. If you have any questions about the review, please contact me at (301) 903-1455, or e-mail: Jehanne.Gillo@science.doe.gov or Dr. James Sowinski at (301) 903-7587, or e-mail: James.Sowinski@science.doe.gov. For logistics questions, contact Elaine Zukowski at BNL at (631) 344-3830 or E-mail: zukowski@bnl.gov.

I greatly appreciate your willingness to assist us in this review. This is a very important process, and it helps to insure the highest quality scientific program at BNL. I look forward to a very informative and stimulating visit.

Sincerely,

Jehanne Gillo
Director
Facilities and Project Management Division
Office of Nuclear Physics

Enclosure

Appendix C: Agenda and List of Reviewers

Relativistic Heavy Ion Collider Science and Technology Review

Agenda

Brookhaven National Laboratory (Instrumentation Large Conference Room)

Tuesday, September 16, 2014

08:00	*DOE Executive session*	
09:00	Welcome	R. Tribble
09:05	ALD Overview • FY12-14 science and facility highlights & impact • Priorities and run plans 2015-22 • Status of sPHENIX project • Long-term vision and transition to eRHIC • Laboratory support • Synergies with Work for Others • Response to recommendations from recent operations and S&T reviews	B. Mueller (40+15)
10:00	PHENIX • New results and accomplishments • Results with VTX and FVTX detectors • Evolution of useful luminosity and high-rate data collection efficiency for PHENIX • PHENIX Decadal Plan	D. Morrison (30+15)
10:45	*Break*	
11:00	STAR • New results and accomplishments • Results from beam energy scan • Results from and plans for future running with HFT, MTD • Evolution of useful luminosity and high-rate data collection efficiency for STAR • STAR Decadal Plan	Z. Xu (30+15)
11:45	RHIC Spin Program	E. Aschenauer

	• Evolution of BNL Spin group • Recent detector and polarimeter improvements • Progress toward Spin strategic plan goals • Future of Drell-Yan spin program • BNL group efforts on EIC spin program	(30+15)
12:30	*Lunch and DOE Executive Session*	
13:45	C-AD operations overview • Status & recent performance of RHIC • Overview of planned upgrades and their impacts on useful luminosity and beam polarization • Progress and risk assessment for ongoing and planned AIP, CE and R&D projects • Management oversight of AIP projects • Operational efficiency • C-AD staffing levels; changes since 2013 Operations Review	W. Fischer (45+15)
14:45	Experiment operations overview • Status of detector upgrades • Assessment of project management and oversight of detector upgrades • Risk assessment for planned MIE and CE projects • Detector (including generic EIC) R&D • Experiment support staffing levels, including new responsibilities and future projections	J. Dunlop (35+15)
15:35	*Break*	
15:50	RHIC Computing Facility • Status of the RCF, synergies with ATLAS Tier-1 • Performance in recent RHIC runs • Future technological and data challenges • Other RCF activities	M. Ernst (20+10)
16:20	Progress toward an Electron Ion Collider Facility • Overview of science case • Accelerator and detector design considerations for eRHIC; transition from RHIC to eRHIC • EIC Advisory Committee recommendations • eRHIC accelerator R&D Strategic Plan; status and scope of activities; CeC Proof-of-Principle	T. Roser (30+10)

	• Timeline for future developments	
17:00	*DOE Executive Session*	
18:00	*Homework Questions for BNL*	

Wednesday, September 17, 2014

08:30	Overview of BNL Nuclear Theory efforts (I) • Recent personnel changes and staffing plans • Recent science highlights and assessment of progress toward goals from 2011 S&T Review • Leadership efforts on EIC science	R. Venugopalan (20+10)
	BNL Nuclear Theory efforts (II) • Recent highlights and plans in Lattice QCD • BNL hardware usage and plans • Synergies with RBRC and HEP theory efforts	F. Karsch (10+5)
9:15	BNL STAR group efforts • Group composition and staffing plans; collaboration leadership positions • Research and operations effort breakdown • Electronics support staffing level and needs • FY13-14 science highlights and research plans • Upgrade involvement and leadership • Research relevant to EIC physics case	F. Videbaek (20+10)
9:45	BNL PHENIX group efforts • Group composition and staffing plans; collaboration leadership positions • Research and operations effort breakdown • Electronics support staffing level and needs • FY13-14 science highlights and research plans • Upgrade involvement and leadership • sPHENIX project management	P. Steinberg (20+10)
10:15	*Break*	

10:30	Status of sPHENIX Project	E. O'Brien (30+10)
11:10	Answers to homework questions	B. Mueller (25+15)
11:50	Safety management in the RHIC program • Interaction with BNL Integrated Facility Management • Injury/incident statistics	E. Lessard (15+5)
12:10	Report from RHIC Users Executive Committee • Interactions with RHIC management • Involvement of users in development of future strategy • Report from Users Meeting • User issues	P. Sorensen (15+5)
12:30	*Lunch and DOE Executive Session*	
14:00	*Parallel breakout sessions, as follows – no formal presentations, just discussion among reviewers and staff*	
	Berkner Room A: *Accelerator operations and development*	W. Fischer I. Ben-Zvi V. Litvinenko V. Ptitsyn M. Brennan M. Blaskiewicz
	Berkner Room B: *Experimental program and theory*	Z. Xu D. Morrison E. Aschenauer W. Christie R. Venugopalan F. Karsch J. Qiu
	Berkner Room C: *Facility management and project oversight*	B. Mueller D. Lissauer T. Roser

		J. Dunlop E. O'Brien P. Pile
16:00	*DOE Executive Session*	
18:00	*Additional homework questions for BNL*	
19:30	*Dinner for Review Panel and Speakers*	

Thursday, September 18, 2014

08:30 Questions and answers with Laboratory Management

09:30 DOE executive session and report writing

13:00 Close out

13:30 Adjourn

Relativistic Heavy Ion Collider
Science & Technology Review
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